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ON ELASTIC-PLASTIC ANALYSIS OF AN OVERLOADED BREECH RING USING NASTRAN

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The piece-wise linear analysis option of the NASTRAN code was used to analyze a photoplastic model for sliding breech mechanism. A two-dimensional finite element representation for the breech ring was chosen and the material was made of polycarbonate resin. The aluminum block was regarded as rigid and the width of contact was assumed to remain unchanged during loading. The displacements and stresses in the breech ring were obtained for loading in
(CONT'D ON REVERSE)

20. ABSTRACT (CONT'D)

the elastic as well as plastic range. The maximum tensile stresses before and after complete unloading were obtained and compared with numerical and experimental results.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

In guns with a sliding breech mechanism, breech ring failures have been observed originating from the lower fillet in the vicinity of the contact region. The observations indicate that high tensile stress produced by stress concentration at the fillet was responsible for the failure. In order to reduce the chance of failure and extend the fatigue life, an exploratory study was initiated on the autofrettage of a breech mechanism. The technique is based on the production of beneficial residual stresses through coldworking to counteract the high operating stresses induced by firing.

A photoplastic model made of aluminum block and polycarbonate ring was designed.[1] The maximum fillet stresses for an elastic load, as well as an elastoplastic load, were determined experimentally. Residual stress resulting from removing maximum test load was calculated. Two numerical investigations of the photoplastic model were made by using NASTRAN[2] and a different finite element program.[3] The latter numerical results are in good agreement with the experimental data in the elastic as well as plastic range of loading.[4]

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[1]Cheng, Y. F., "Photoplastic Study of Residual Stress in an Overloaded Breech Ring," ARRADCOM Technical Report No. ARLCB-TR-78018, Benet Weapons Laboratory, Watervliet, NY.
[2]Chen, P. C. T. and O'Hara, G. P., "NASTRAN Analysis of a Photoplastic Model for Sliding Breech Mechanism," Proceedings Army Numerical Analysis and Computer Conference, pp. 237-254, September 1979.
[3]Chen, P. C. T., "Numerical Prediction of Residual Stresses in an Overloaded Breech Ring," Proceedings of the Army Numerical Analysis and Computer Conference, pp. 333-346, August 1980.
[4]Chen, P. C. T. and Cheng, Y. F., "Stress Analysis of an Overloaded Breech Ring," Proceedings of the International Conference on Reliability, Stress Analysis, and Failure Prevention, pp. 175-180, August 1980.

This report describes the NASTRAN analysis of a photoplastic model and gives an assessment of the NASTRAN code. The NASTRAN results for the maximum tensile stress are determined as a function of loading beyond the elastic limit. The loading range in which the NASTRAN program can be applied has been determined. Beyond this range, the values for the maximum tensile stress and the residual stress are estimated and compared with other numerical[3] and experimental[1] results at the maximum load level.

MODEL AND LOADING

A two-dimensional photoplastic model of aluminum block and polycarbonate ring was designed.[1] The breech ring made of 0.12 inch thick LEXAN plate and the top of the ring was fixed. This material has a Poisson's ratio of 0.38 in the elastic state and a limiting value of 0.5 in the plastic state. The stress-strain (σ-ε) curve for LEXAN can also be described by the modified Ramberg-Osgood equation in the following form

$$E\varepsilon/\sigma_B = \sigma/\sigma_B + (3/7)(\sigma/\sigma_B)^n \quad \text{for} \quad \sigma_A < \sigma < \sigma_C \qquad (1)$$

and the values of five parameters are E = 325 Ksi, n = 11.5, σ_A = 6.2 Ksi, σ_B = 8.7 Ksi, σ_C = 9.576 Ksi, where E is Young's modulus, n is a parameter, σ_A is the proportional limit, σ_B is the secant yield strength having a slope equal to 0.7 E and σ_C is the flow stress at which the slope of the stress-strain is zero.

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[1]Cheng, Y. F., "Photoplastic Study of Residual Stress in an Overloaded Breech Ring," ARRADCOM Technical Report No. ARLCB-TR-78018, Benet Weapons Laboratory, Watervliet, NY.
[3]Chen, P. C. T., "Numerical Prediction of Residual Stresses in an Overloaded Breech Ring," Proceedings of the Army Numerical Analysis and Computer Conference, pp. 333-346, August 1980.

Figure 1 shows a finite element representation for one half of the breech ring. The other half is not needed because of symmetry. There are 224 grids and 189 quadrilateral elements in this model. The grids 1 through 8 are constrained in x-direction only while grids 233 through 240 are held fixed. The top portion of the breech ring is omitted because this is believed to have little effect on the maximum stress information near the lower fillet. In fact this belief has been confirmed by obtaining the elastic solution for another finite element model with additional 70 quadrilateral elements in the top portion. The differences between these two models for the maximum tensile and compressive stresses are 1.3%, 3.3%, respectively. The aluminum block is regarded as rigid and the load is transmitted to the ring through contact. Initially the block is in full contact with the ring. As load increases, a gap develops in the central portion. The width of the central gap under the full test load of 572 pounds is observed experimentally to be about five inches. NASTRAN program in its present form cannot be used to determine the width of contact and the force distribution as functions of loading. In this numerical investigation, several contact conditions are chosen and assumed to remain unchanged during loading.

ELASTIC SOLUTION

Since the width of contact and the force of distribution are not to be determined as functions of loadings, eight contact conditions under different prescribed displacements or forces are tried. The displacements and stresses in the elastic range for all cases are obtained. Three cases are under uniform prescribed displacements; case 1 at nodes (33,41,49,57), case 2 at nodes (49,57,65), and case 3 at nodes (57,65,81). Five cases are under prescribed forces; case 4 (20,50,30 lbs.) at nodes (49,57,65), case 5 (63.13, 36.87 lbs.) at nodes (57,65), case 6 (100 lbs) at node 65, case 7 (50,50 lbs.) at nodes (65,81), case 8 (12.5, 25,25,25,12.5 lbs.) at nodes (57,65,81,89,97). It is interesting to find out that the location of the maximum tensile stress is in element 155 for all cases and agrees very well with the experimental observation. The constraint forces for the three cases under prescribed displacements are calculated. If the total contact force F is 100 pounds, the magnitudes of the maximum tensile stress for 8 cases are 1801, 1847, 1869, 1842, 1840, 1853, 1873, 1916 psi, respectively. It should be noted that the stresses in the NASTRAN program are calculated at the centroid of each element but only one principal stress at the force boundary can be measured. The experimental result for the maximum tensile stress at the fillet 2222 psi per 100 pounds of load in the elastic range. For the purpose of comparison, the boundary stress is determined by extrapolation using the calculated results for those elements along the radial direction through element 155. This is shown in Figure 2 for case 4. It seems that the numerical result agrees very well with the experimental data in the elastic range of loading.

The stress outputs of the NASTRAN program are σ_x, σ_y, τ_{xy}, β, σ_1, σ_2, τ_m at the centroid of each element where σ_x, σ_y, τ_{xy} are the stresses in element coordinate system (x,y); β is the principal stress angle; σ_1 and σ_2 are the major and minor principal stresses; and τ_m is the maximum shear. Since our stress results are stored on tape, we can retrieve them to calculate the octahedral shear stress (τ_o), the effective stress (σ_o), the stresses in global coordinate system ($\bar{\sigma}_x$, $\bar{\sigma}_y$, and $\bar{\tau}_{xy}$) and we can also calculate the residual stresses after complete unloading from various stages of loadings. The formulas for the above calculations are

$$\tau_o = (\sqrt{2}/3)\sigma_o = (S_x{}^2 + S_y{}^2 + S_2{}^2 + 2\tau_{xy}{}^2)^{1/2} \quad ,$$

$$S_x = (2\sigma_x - \sigma_y)/3 \quad , \quad S_y = (2\sigma_y - \sigma_x)/3 \quad ,$$

$$S_z = -(\sigma_x + \sigma_y)/3 \quad , \quad \Theta = \alpha - \beta \quad ,$$

$$\bar{\sigma}_x = 1/2(\sigma_1 + \sigma_2) + 1/2(\sigma_1 - \sigma_2)\cos 2\Theta \quad ,$$

$$\bar{\sigma}_y = 1/2(\sigma_1 + \sigma_2) - 1/2(\sigma_1 - \sigma_2)\cos 2\Theta \ ,$$

$$\bar{\tau}_{xy} = -\ 1/2(\sigma_1 - \sigma_2)\sin 2\ \Theta \tag{2}$$

where α is the angle of the global coordinate system with respect to the element coordinate system.

ELASTOPLASTIC SOLUTION

Only two of the eight contact conditions considered in the elastic range have been extended into the plastic range. They are case 1 under prescribed displacements and case 4 under prescribed forces. RIDIG FORMAT 6 of the NASTRAN Code is used in both cases. However, for problems under prescribed displacements, the DMAP sequence should be slightly modified. The maximum contact displacement at grid points 33, 41, 49, and 57 is set as 0.089 inch. This magnitude is to be reached in 15 incremental steps defined by PLFACT card. Since no actual applied forces are involved, a dummy force card together with its related information should be provided. The contact force F is the sum of the vertical components of the constraint forces under contact. The results for F at the first 12 load levels are 203, 265, 324, 353, 382, 411, 439, 467, 490, 512, 533, 544. The NASTRAN program stops at load level 13 with the error message - "stiffness matrix singular due to material plasticity". The relation between the contact force and the contact displacement is almost linear as shown in Figure 3. We have examined the stresses in all elements and the results show that the maximum tensile stresses occur in element 155. This location remains unchanged as load increases. Therefore, we plot the stresses in this element as functions of loading history as shown in Figure 3. At F = 544 pounds, $(\sigma_1, \sigma_2, \sigma_o) = (10750, 1656, 10025)$ psi in element 155. Since the NASTRAN program stops at load level 13, it fails to give any information for loading larger than 544 pounds. However, it does show that the stresses in element 155 remain unchanged after the contact force F reaches 533 pounds. The residual stresses after complete unloading from various stages of loadings are calculated and these results for σ_1 in element 155 are shown also in Figure 3. The residual stress σ_1 is still in tension if unloading from the early stages of loadings. This is undesirable. If the contact force is larger than 533 pounds, then the residual stress decreases. The octahedral shear stress τ_o is used to determine the size of the plastic zone under various loading levels. The plastic zone at F = 544 pounds is shown as the dark area in Figure 1.

We have also obtained an elastoplastic solution for the problem under prescribed forces at nodes 49, 57, and 65. The distributions of forces at these three points are assumed to be 20, 50, 30%, respectively. We have applied the forces of F = 240, 300, 350, 400, 450, 500, 524, 548, 572 pounds. The NASTRAN program stops at the last load level with the error message - "stiffness matrix singular due to material plasticity". It is interesting to observe that when the contact force increased from 524 to 548 pounds, the stresses in element 155 remain unchanged and the values for σ_1, σ_2, σ_o, are 10603, 1562, 9914 psi, respectively. We may make a conjecture that a constant state of stress in element 155 is reached after the contact force reaches 524 pounds. The results for the stresses (σ_1, σ_2, τ_o) in element 155 as functions of contact forces are shown in Figure 4. The residual stresses after complete unloading from various stages of loading can be calculated and the results for σ_1 are also shown in Figure 4. For the purpose of comparison, this problem under the same loading conditions has been solved using a different finite element program.[3] The results for the maximum tensile stress σ_1 and the residual stress σ_1 are shown by the dotted lines in Figure 4. The results are quite different from those based on the NASTRAN program. The residual stress σ_1 is element 155 after unloading from maximum test load (F = 572 lbs.) is about zero based on the NASTRAN results as shown in Figures 3 and 4 while the other numerical result[3] is about 2000 psi in compression.

It should be noted that the stresses in the finite element programs were calculated at the centroid of each element but only one principal stress at the boundary was measured. The values of the maximum tensile stress at the fillet based on the experimental approach are 2222 psi at F = 100 pounds and 9300 psi at F = 572 pounds. For comparing with experimental results, the boundary stress is determined by extrapolation using the calculated results for those elements along the radial direction through element 155. This is illustrated in Figure 5 for the fourth case of contact condition using the

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[3]Chen, P. C. T., "Numerical Prediction of Residual Stresses in an Overloaded Breech Ring," Proceedings of the Army Numerical Analysis and Computer Conference, pp. 333-346, August 1980.

computer program in reference 3. Four curves are plotted in Figure 5 and they represent the major principal stress for four load levels. The residual stresses after complete unloading are determined by assuming that the unloading process is purely elastic. Our numerical results reveal no reverse yielding. As seen in Figure 5, a satisfactory agreement has been reached between the experimental and numerical results.[3,4] The NASTRAN result for the maximum tensile stress in the elastic range is 2220 psi for a force of 100 pounds as shown in Figure 2. Assuming that the maximum tensile stress at F = 572 pounds is 10600 psi, the residual stress after complete unloading is estimated to 2100 psi in compression and the experimental result is 3400 psi in compression as shown in Figure 5. There is a definite need to mprove the NASTRAN program for stress analysis in the plastic range especially under large values of loadings.

CONCLUSION

A numerical study on a photoplastic model for sliding breech mechanism has been made by using NASTRAN program. The location and magnitude for the maximum tensile stresses have been determined for loading in the elastic as well as elastoplastic range. In the elastic range of loading, the numerical results are in good agreement with the experimental data. In the elasto-plastic range of loading the NASTRAN program can be used only up to a certain

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[3]Chen, P. C. T., "Numerical Prediction of Residual Stresses in an Overloaded Breech Ring," Proceedings of the Army Numerical Analysis and Computer Conference, pp. 333-346, August 1980.
[4]Chen, P. C. T. and Cheng, Y. F., "Stress Analysis of an Overloaded Breech Ring," Proceedings of the International Conference on Reliability, Stress Analysis, and Failure Prevention, pp. 175-180, August 1980.

load limit. Beyond this limit, the values for the maximum tensile stress and the residual stress after complete unloading can only be estimated. The comparisons with other numerical and experimental results indicate that further investigation on the NASTRAN program is needed for problems involving large plastic deformation.

REFERENCES

1. Cheng, Y. F., "Photoplastic Study of Residual Stress in an Overloaded Breech Ring," ARRADCOM Technical Report No. ARLCB-TR-78018, Benet Weapons Laboratory, Watervliet, NY.

2. Chen, P. C. T., and O'Hara, G. P., "NASTRAN Analysis of a Photoplastic Model for Sliding Breech Mechanism," Proceedings Army Numerical Analysis and Computer Conference, pp. 237-254, September 1979.

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4. Chen, P. C. T. and Cheng, Y. F., "Stress Analysis of an Overloaded Breech Ring," Proceedings of the International Conference on Reliability, Stress Analysis, and Failure Prevention, pp. 175-180, August 1980.

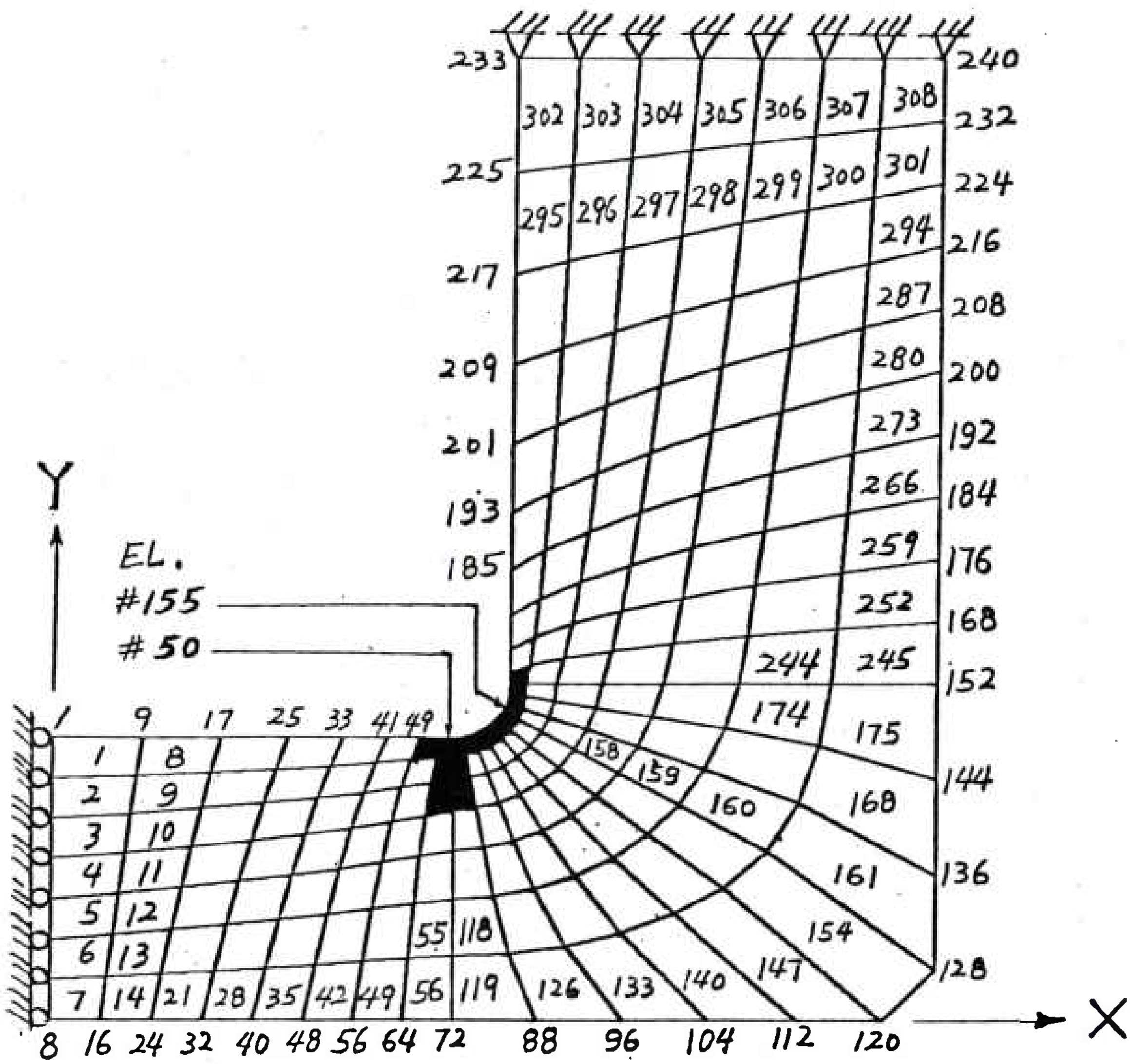

Figure 1. Finite Element Model for Breech Ring.

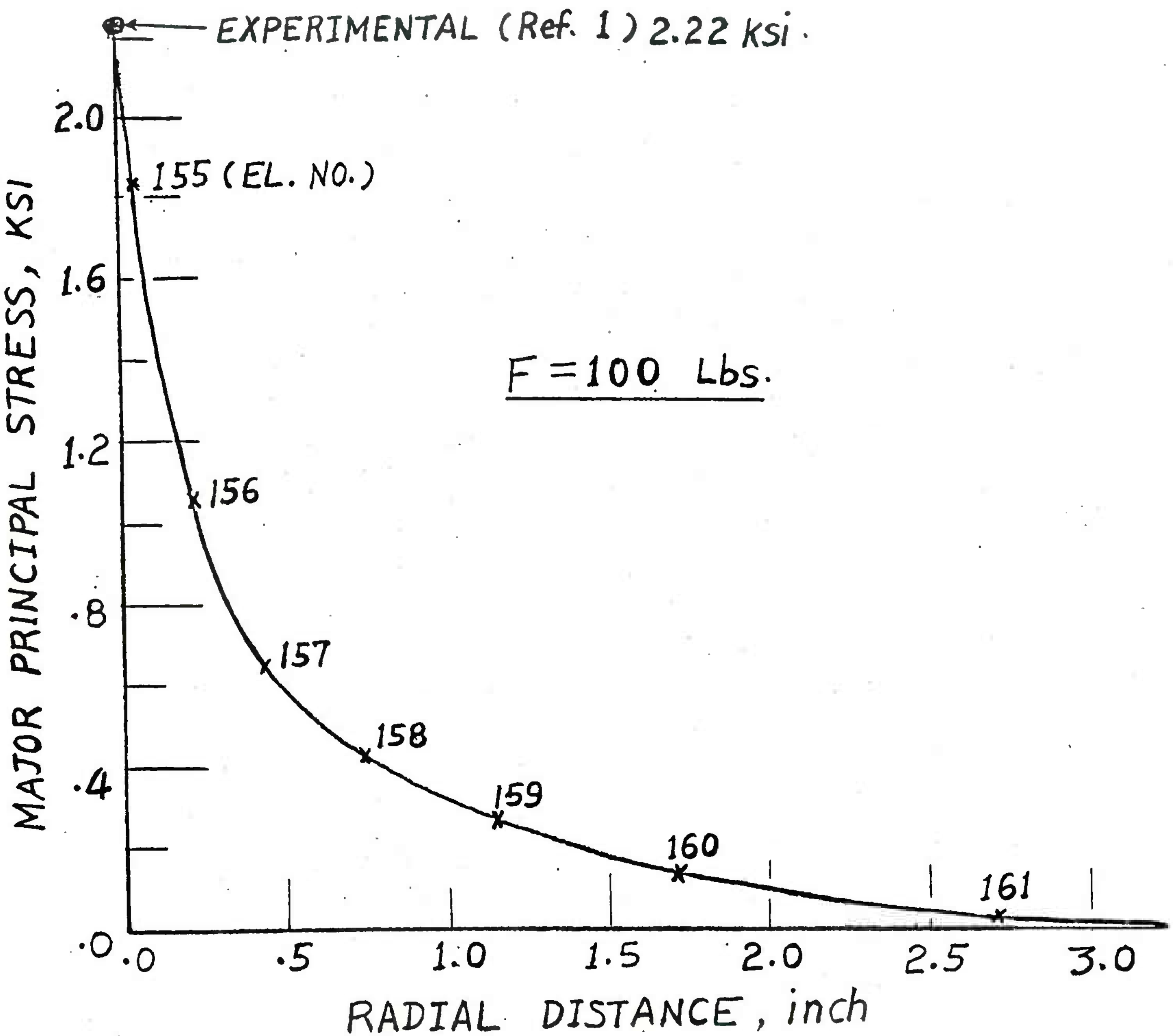

Figure 2. Maximum Tensile Stress for Elastic Loading.

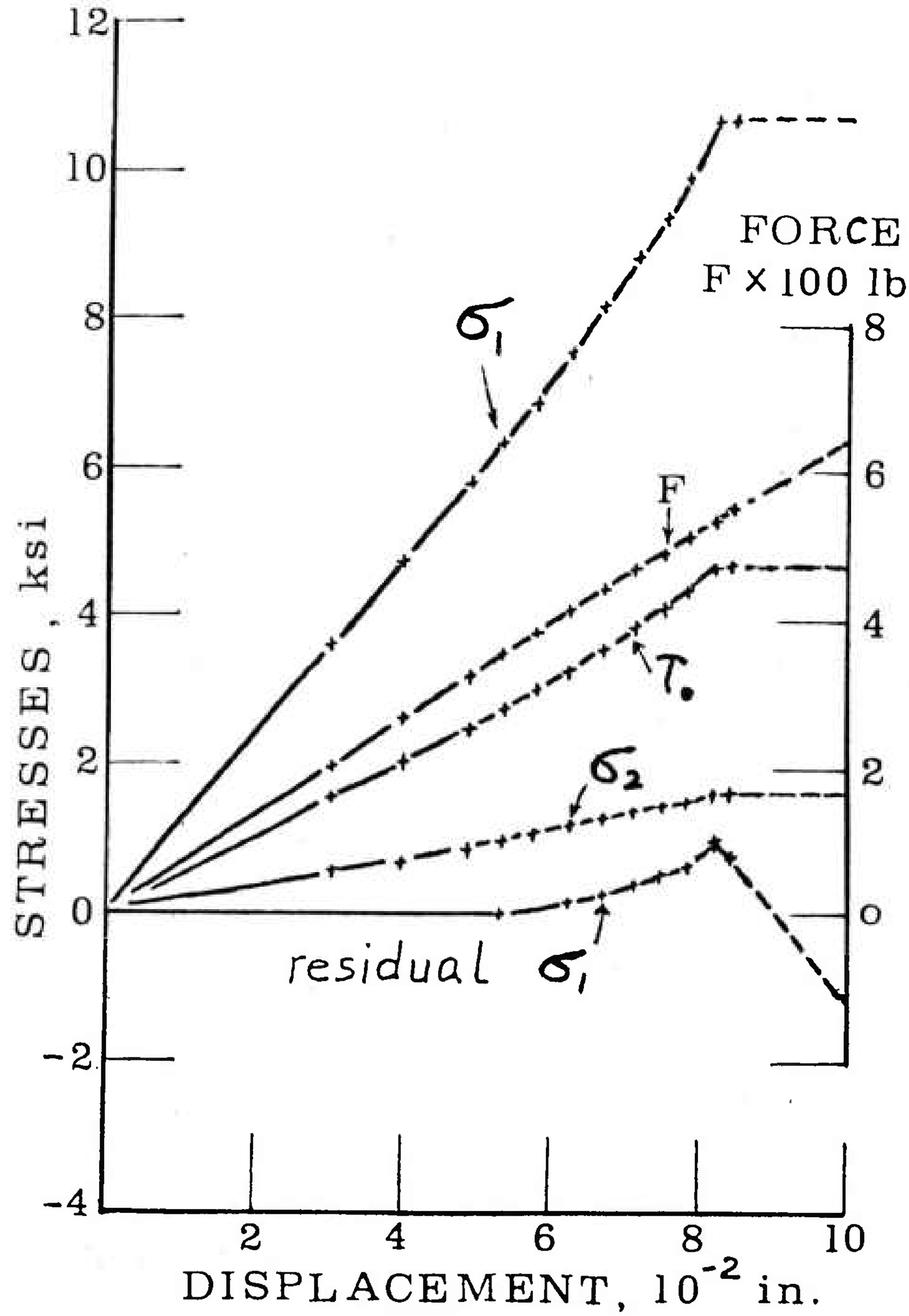

Figure 3. Stresses in Element 155 as Functions of Contact Displacement.

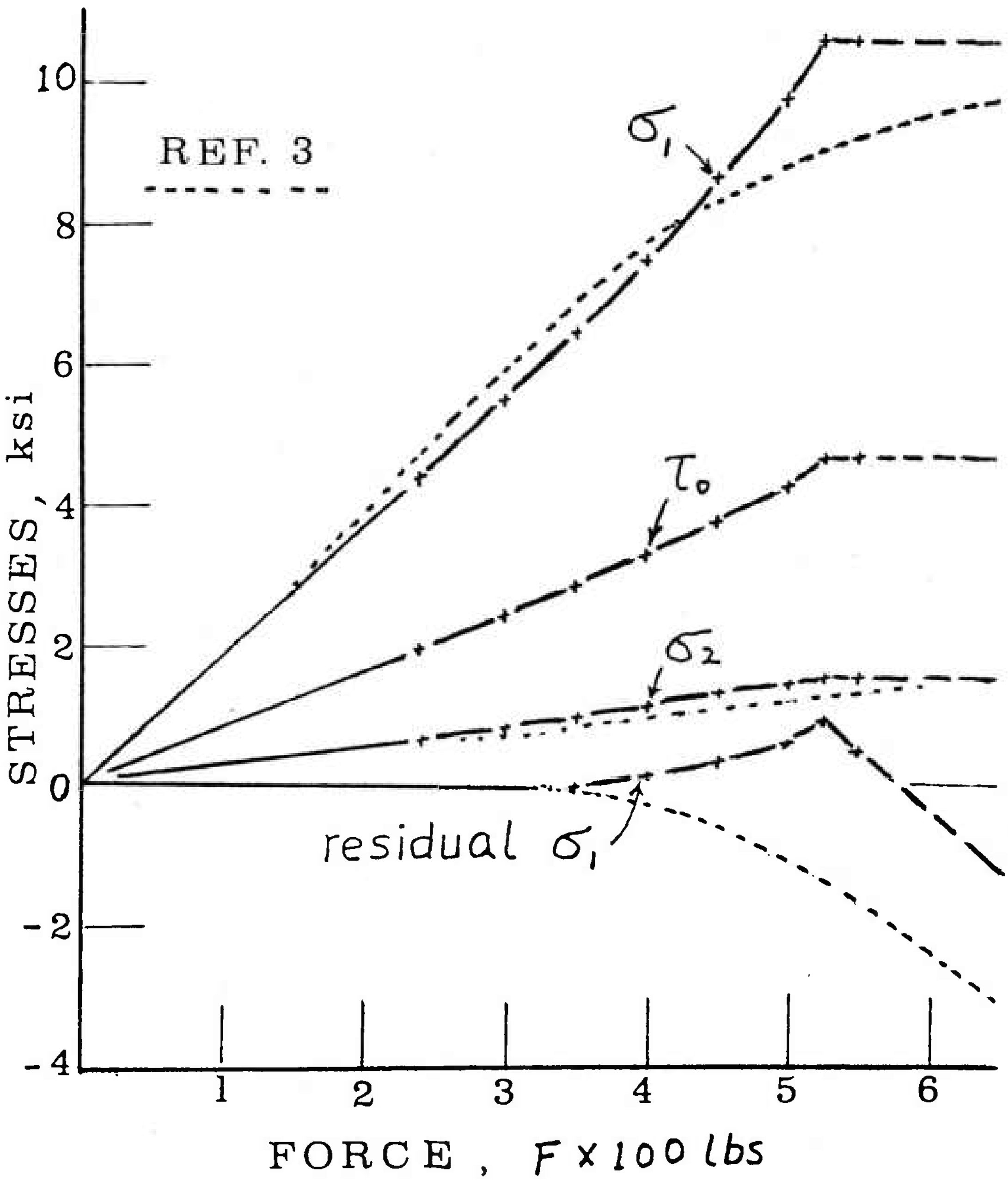

Figure 4. Stresses in Element 155 as Functions of Contact Force.

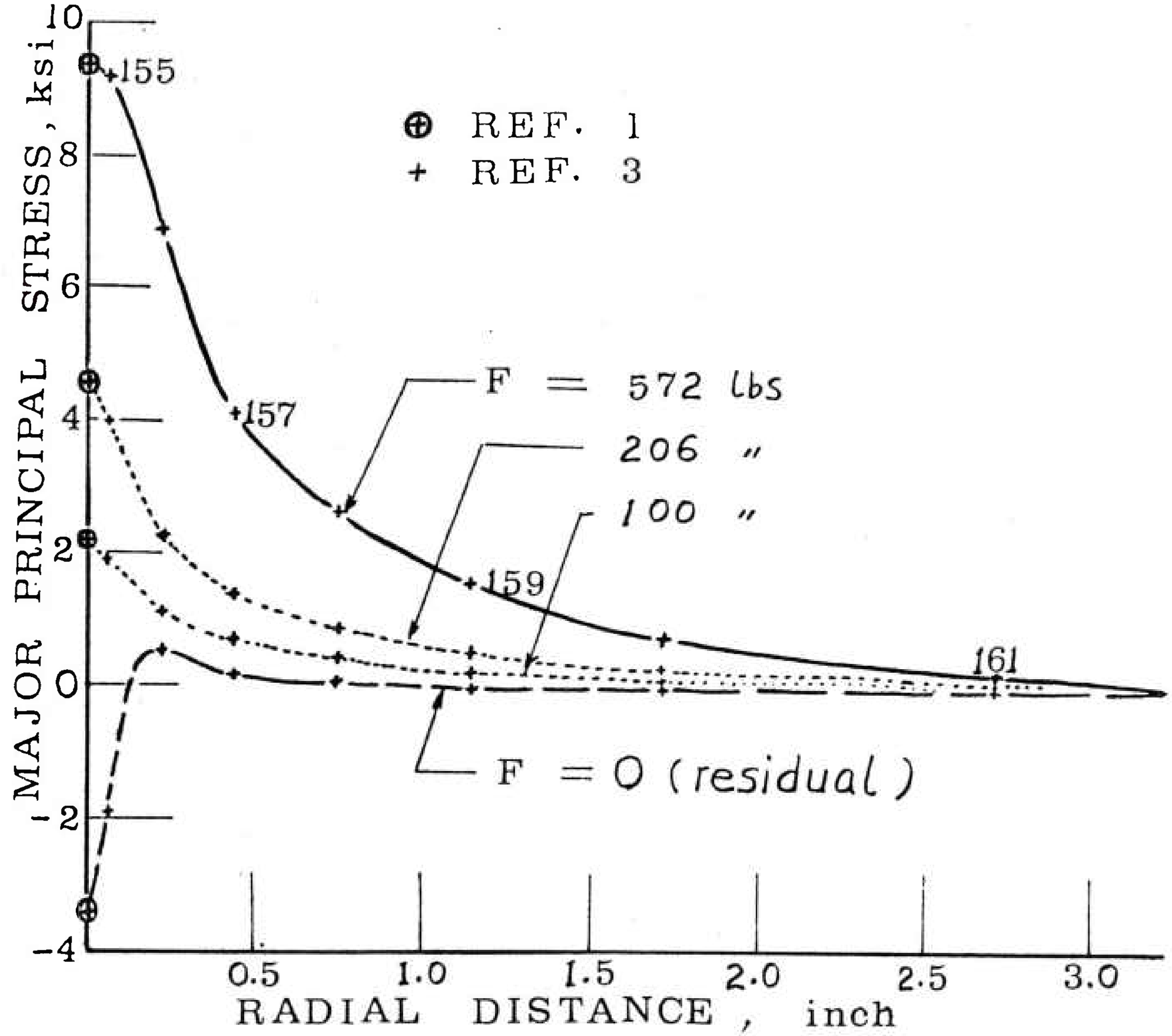

Figure 5. Determination of the Maximum Fillet Stress.

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